Real-Time Forecasting System of Winds, Waves and Surge in Tropical Cyclones

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LONG-TERM GOALS

The long-term goal of this partnership is to establish an operational forecasting system of the wind field and resulting waves and surge impacting the coastline during the approach and landfall of tropical cyclones. The results of this forecasting system would provide real-time information to the National Hurricane Center during the tropical cyclone season in the Atlantic for establishing improved advisories for the general public and federal agencies including military and civil emergency response teams.

OBJECTIVES

1) To define output products necessary to enhance the guidance skills of the Tropical Cyclone Forecast/Advisory product.
2) To test the model infra-structure that would lead toward better forecast information for landfall hurricane wind, wave, and surge conditions. Several historical storms will be used to assess model infra-structure.
3) To develop the interface that couples high-resolution cyclone wind fields to the selected wind model.
4) To develop a system that couples storm surge and spectral wave models driven by winds specified in 6).
5) Test entire system via a proof-of-concepts approach with data from several historical hurricanes.
6) Test system in semi-operational mode during several hurricane seasons and begin transition to fully operational mode.

APPROACH

During this hurricane season we have been testing a proto-type model system for forecasting winds, waves and surge in real time in a pre-operational mode. The focus of the project effort was to implement a fully automated, operational model forecasting system that is capable to download input data (Hwind from NOAA/AOML) for initializing the wind fields as well as all in-situ buoy station and satellite data to generate wind fields for a five day forecast. The real-time fields of forecasted wind and pressure variables were applied as forcing fields in wave and hydro-dynamical (storm surge) models. The model computations were completed within 60 minutes and the entire cycle was repeated every six hours to simulate the advisory cycle of the National Hurricane Center.

A project approach was described in previous reports.

WORK COMPLETED

1. Completed current hurricane season in fully automated, but semi-operational mode.
2. The WINDGEN system has performed very well during the most recent hurricane season. The system is ready for operational use.
3. Wave and surge models have been coupled to include the effect of momentum input from breaking waves on sea-level rise in coastal regions.
4. Tidal dynamics have been integrated into the surge predictions.
5. Surge model has been integrated into forecast system to run in real-time for the 2004 hurricane season (for all storms, but specifically for Charlie, Frances, Ivan and Jeanne).

RESULTS

Wind Field Generation Program: The WINDGEN program is in its second iteration and has been successfully applied during the 2004 hurricane season. The program can input either Hwind analysis or perform its own wind field generation using the TC96 tropical boundary model. The program also provides wind/pressure output for numerous alternate track models for use by the modelers. The WINDGEN program queries external data sources for the acquisition of track, Hwind, background fields and alternate track information. In addition, validation data from NDBC (National Data Buoy Center) is being ingested in real time. All scripts have been running throughout the hurricane season and are performing well.

Three data sets of wind stress measurements in hurricane force winds were obtained in the Air-Sea Interaction Facility using the profile method, the Reynolds stress method, and the momentum budget or "surface slope" method. The excellent agreement among the various methods validates the momentum budget method which, being insensitive to air-borne droplets, allows us to measure the surface stress at the highest winds generated. Here we see the characteristic behaviour of the drag coefficient as the surface condition goes from aerodynamically smooth (characterized by a drop in the drag coefficient with increasing wind) to aerodynamically rough (drag coefficient increasing with wind speed). Unlike a solid surface, the roughness elements (or waves) are themselves responsive to the wind so that the drag coefficient increases between 3 and 33 m/s as shown in Figure 1.

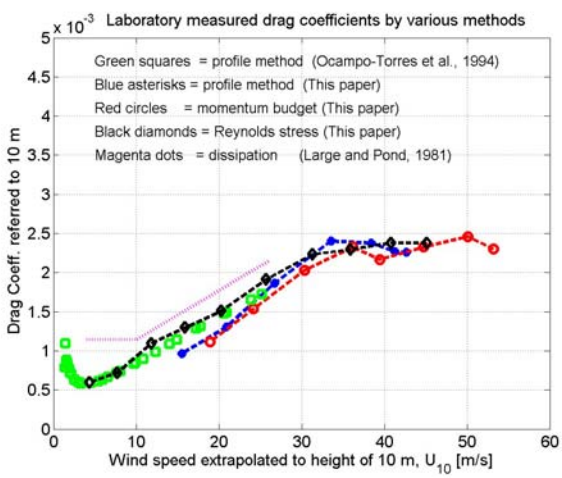

Figure 1: Laboratory measurements of the drag coefficient by profile, eddy correlation ("Reynolds") and momentum budget methods for winds ranging to hurricane force strength.

Wave Modeling: A fully tested and automated, operational wave forecasting system based on WAM Cycle 4.5 for Hurricanes at Landfall was put in place for the 2004 Hurricane season. Initial testing was performed with the season's first storm Alex and by the time Bonnie, and Charley emerged in the Gulf of Mexico, the system was capable of generating 5-day forecasts producing output product files for subsequent use in graphical display. Significant effort was devoted to optimizing WAM Cycle 4.5 in collaboration with IBM's T.J. Watson Center for improved computational performance on the IBM p690 system using OpenMP. While this effort continues, the run times for the operational domain (-99° to -30° W / 5° to 53° N) have been reduced by a factor of two despite increase in the operational domain by 25%. The significant improvements will enable the wave forecasting system to run 4 to 8 alternate hurricane track within the advisory cycle and on the current configuration of the IBM p690 Regatta. The results will be used to produce ensemble averaged output products in a timely manner. Work continues on this task to improve the optimization gaining valuable time. Automated system was running stable four times per day for Frances. After that time we added validation of the wave results to point source measurements such as buoys. The validation was carried out on a manual basis for Hurricane Ivan. What this provides is near-real time feedback of the wave results, identifying areas where the model physics (collaborative effort with the CBLAST Project) need to be improved, potential sources of wind field inaccuracies and more importantly providing credibility to the results being posted on our web.

Surge Modeling: We have integrated the ADCIRC (Advanced Circulation Model for Coasts, Shelves and Estuaries, Luettich, et al., 1992) with the WAM3G Cycle-4 model to improve predictive skill for storm surge during tropical cyclones. This approach has been tested for hurricane Georges (1998) and hurricane Isabel (2003), and has been running in real-time for the 2004 hurricane season. Further significant progress was made by establishing a tidal data set which was verified and implemented in the real-time forecasting system for the entire Western North Atlantic Tidal (WNAT) model domain, which includes coastal and open ocean waters west of the 60° W. Now each five-day forecast includes astronomical tides. The accuracy of the current 31,435-node mesh is not optimal for tides, but serves well in the prototype system. An unstructured mesh with 333,701 nodes was shown to be within 10 degrees phase and 10% amplitude at nearly all of more than 100 tidal stations. That mesh was employed in an extensive truncation error analysis procedure to produce a 52,774-node mesh that equals or out-performs its over-resolved predecessor. Finally, an analysis on the influence of floodplains with respect to accurate storm tide modeling was performed using a wind field hindcast of Hurricane Hugo.

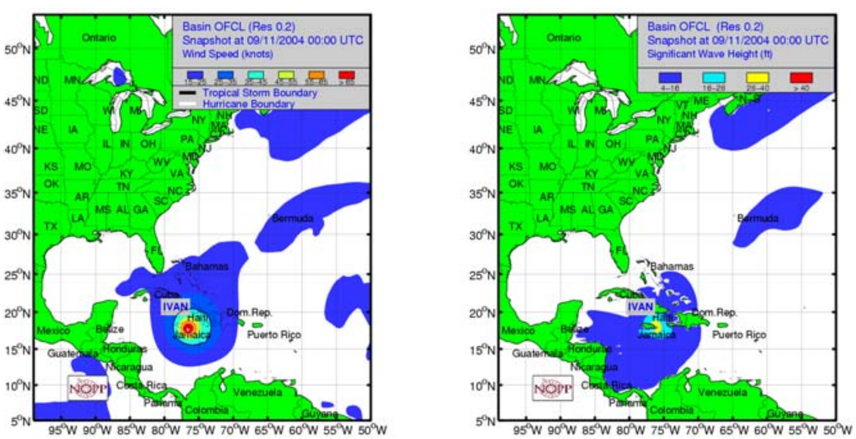

Figure 2: Examples of wind and wave products generated in real time for Hurricane Ivan.

IMPACT/APPLICATIONS

An improved forecast of the coastal environment under hurricane conditions has potential benefit for society in several areas. A primary benefit is the early warning and evacuation of population and mobile assets from threatened coastal areas. The storm surge modeling can also be extended to include tsunami prediction and warning capabilities.

National Security

Improved forecasting of several days in advance will help emergency planners and FEMA as well as DHS to prepare adequately for approaching tropical cyclones.

Economic Development

This forecast system could also be used to determine which coastal regions are extremely vulnerable to the impact of tropical cyclones especially caused by flooding and wave damage. New risk and exposure maps for flooding can readily be generated with the added benefit of risk factors, i.e. not all storm may lead to flooding.

Quality of Life

Understanding better the risk to potential damage will allow the public and communities to make decisions on where to live and how to manage coastal and ecological resources.

Science Education and Communication

Assessment of operational models will identify shortcomings in the science and physics of models used for weather prediction as well as the need for the right data at critical locations and times.

TRANSITIONS

National Security

We are exploring to implement the system at the Joint Typhoon Warning Center in Hawaii to cover the Pacific Ocean especially the western portion of the Pacific.

RELATED PROJECTS

This NOPP project began to partner with SCOOP whose primary goal is to provide high-resolution storm surge predictions during severe weather phenomena such as tropical and extra-tropical storms in coastal regions along the US East coast and Gulf of Mexico. To achieve this goal SCOOP will utilize the NOPP's coupled model forecast system. Two studies started that target specific coastal and inland regions. First, a study with the NWS Southeast River Forecast Center to produce real-time tides and storm tide hydrographs for the Waccamaw River region in South Carolina. In addition, NOAA, through the NWS Office for Hydrologic Development has funded a three-year. A collaborative effort between UCF and UF led to a pilot study for the Florida Department of Transportation (FDOT), which will examine the effects that inlet shapes, as well as coupled short and long wave models have on nearshore storm tide hydrographs that are then employed in bridge scour studies.

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